REPORT ON PRELIMINARY RESEARCH RESULTS:

ECOLOGICAL EFFECTS OF FIRE ON TROPICAL CLOUD FOREST IN THE CHIMALAPAS REGION; OAXACA, MEXICO

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1. OVERVIEW AND OBJECTIVES

Fire is increasingly becoming a major disturbance phenomenon in tropical moist forests, propelled by climate change and growing pressures from anthropogenic activities (Whitmore and Burslem 1998). This trend is likely to produce compounded, synergistic effects on long-term ecosystem functioning, biological diversity, global biogeochemical cycles, and the sustainability of human societies (Paine et al. 1998). Our understanding of ecosystem functioning in *undisturbed* tropical moist forests has rapidly expanded during the past two decades due to an increase in ecosystem-based research initiatives (Bruijnzeel 1980, Denslow 1980, Tanner 1985, Lawton and Putz 1988, Veneklaas 1991, Delaney et al. 1997, 1998, Bruijnzeel and Veneklaas 1998, Nadkarni et al. 2000, Clark et al. 2001). In contrast, there exists a paucity of empirical data on the ecosystem-scale impact and long-term implications of large-scale disturbance by wildfire in the moist tropics. Most research on fire in tropical moist forest ecosystems has focused on recovery processes following logging (Nepstad et al. 1999) or slash-and-burn agriculture and grazing (Stocker 1981, Woods 1989, Aide et al. 1996, Malmer et al. 1996, Miller and Kauffman 1998, Kammesheidt 1999), or on the ecological effects of fire on vegetation dynamics (Nykvist 1996, Pinard and Huffman 1997, Pinard et al. 1999). More recently, ecosystem-based research on fire in *dry* tropical forests has documented significant losses in nutrients and organic matter from both soils and vegetation (Kauffman et al. 1993, García-Oliva et al. 1999), and has led to hypotheses that fire may eventually push these ecosystems to lower states of functioning (Finegan 1996, Mack and D'Antonio 1998, Cochrane et al. 1999). However, there is a significant gap in our knowledge base about the resistance and resilience of *moist* tropical forest ecosystems to fire, and the processes and mechanisms by which these ecosystems are able to recover the structure and functions required for long-term sustainability. Lack of such knowledge impedes our ability to design management, conservation, and restoration strategies that effectively address the unique conditions existing in burned and fire-threatened landscapes in tropical moist forest regions.

Our *long-term goal* for this research is to determine the resistance and resilience of tropical moist forest ecosystems to large-scale disturbance by wildfire and predict future changes in ecosystem functioning as a basis for designing more effective management, conservation, and restoration strategies. As the next step towards achieving this goal, the *objective* of the proposed research is to quantify the key ecosystem processes and mechanisms contributing to the recovery of structure and function in tropical moist forest ecosystems following wildfire. Our *central hypothesis* is that these recovery processes and mechanisms will be strongly determined by differences in ecosystem productivity, burn intensity, and individual species' physiological responses, as influenced by altitudinal, climatic, and physiographical constraints. This hypothesis was developed based on preliminary field observations and data collected from the proposed research site (Gallardo-Hernández et al. 2000, Asbjornsen et al. 2001, Naess 2001), and critical analysis of this new information within the context of existing knowledge on large-scale, infrequent disturbances in both temperate (Zackrisson et al. 1996, Neary et al. 1999, Turner et al. 2001) and tropical (Zou et al. 1995, Zimmerman et al. 1995, Waide and Lugo 1992b) ecosystems. The *rationale* for the proposed research is that this knowledge will promote more effective policies and management interventions for modulating the negative impact of fire in the moist tropics. Our research team is well qualified to undertake the proposed research due to extensive preliminary assessments conducted by our team at the field site during the past 20 months that have enabled us to develop strong hypotheses, experimental design, and methodological approach. Further, we comprise an interdisciplinary team with expertise from diverse fields required to successfully test these hypotheses and achieve the dissemination and application of the research results, including ecosystem ecology, botany, hydrology, soil science, sociology, anthropology, and natural resource management. The combined research facilities at the collaborating academic institutions support the infrastructure and equipment needed to conduct the requisite field work and laboratory analysis for this research.

We plan to test our central hypotheses and accomplish the overall objective of this application by pursuing the following three specific objectives and working hypotheses:

1. ***Determine the processes and mechanisms of ecosystem recovery following wildfire in tropical moist forests occurring along an altitudinal gradient.***
   Working Hypothesis: The recovery of ecosystem structure and function will be more rapid in highly productive ecosystems as compared to less productive montane ecosystems due to slower cycling of nutrients and energy in the latter, and the greater prevalence of biotic and abiotic mechanisms that enhance ecosystem resistance and resilience in the former.
2. ***Assess the effect of different burn intensities associated with altitudinal and topographical gradients within the landscape on the recovery of tropical moist forests.***
   Working Hypothesis: Sites affected by less severe burn intensities will recover more rapidly compared to sites affected by high burn intensities due to greater loss of nutrients and soil organic matter and reduction in available plant response mechanisms under higher burn intensities.
3. ***Promote active participation of multiple stakeholders and effective application of research results in order to achieve local and regional management objectives.***
   Working hypothesis: The integration of research and management based on a participatory, interdisciplinary approach will enhance communication and understanding of the issues, catalyze collaborative partnerships among diverse stakeholders and, in turn, lead to more effective strategies for disseminating and applying research results to solving management problems.

This research is expected to yield the following outcomes: First, the processes and mechanisms of recovery of burned tropical moist forest ecosystems will be quantified and the long-term resistance and resilience of these ecosystems assessed. This information is important because it will provide a measure of the ecosystem's capacity to maintain key ecological functions for sustaining both human and biological systems in the region. Second, the effect of different burn intensities on ecosystem recovery will be evaluated, which is important for accurately documenting ecosystem recovery patterns following fire on the landscape scale. Third, active participation and collaboration among diverse stakeholders will catalyze new partnerships having an enhanced understanding of fire in tropical moist forests, thereby strengthening their capacity to effectively confront fire-related management challenges. Collectively, these outcomes will establish a knowledge base about the ecological implications of wildfire in tropical moist forest ecosystems on multiple scales, and the integration of this information into decision-making processes that significantly address the threats posed by the growing prevalence of fire in moist tropical regions. The fundamental new knowledge generated and applied by this research will provide a model for managing and restoring fire-affected moist tropical forests and regulating the use of fire as a management tool at the local community, regional, and global levels.

Expected significance of the proposed research

There exists a critical lack of knowledge about the ecological effects and dynamic role of fire in moist tropical ecosystems. Furthermore, it is evident that new and innovative approaches are required to link ecological information obtained at different scales, while concomitantly addressing the integration of research and management through participatory, interdisciplinary approaches. The proposed research will determine how the increasing occurrence of wildfire in tropical moist forest ecosystems is affecting long-term ecosystem functioning and sustainability, and establish a methodological approach for interdisciplinary, participatory research to strengthen the link between improving the knowledge base and informed decision-making related to the management of fire-affected and fire-prone landscapes. Various benefits are expected to be engendered by this research. First and foremost, this research will enhance our theoretical understanding of ecosystem dynamics and the ecological implications of disturbance by fire in moist tropical forest ecosystems. Equally important, the congruent dissemination and application of the research results will directly influence policy and management on several different levels: communities situated within or near watersheds affected by fire will obtain information needed to develop management plans that more effectively promote the recovery of fire-affected areas and the sustainability of both human and natural ecosystems in the landscape; on the regional scale, the research will contribute to the formulation of policies that address watershed and landscape change due to fire, and actively promote interventions to mitigate or prevent negative consequences of past and future fires; finally, on a global basis, more accurate predictions of the potential influence of fire in the moist tropics on global phenomena will stimulate more proactive and scientifically-supported negotiations on international policies for promoting more positive and healthy interactions between humans and fire.

2. GENERAL BACKGROUND

Prior to the 1980s the issue of fire in humid tropical forests would have been considered an oxymoron. The assumption was that the seemingly ever-moist condition of the soils and vegetation and abundant rainfall and atmospheric humidity prohibited these ecosystems from burning, while the possibility of extensive and uncontrolled wildfires occurring seemed even more remote. Consequently, the extensive wildfires that affected Borneo and other parts of Southeast Asia during the El Niño induced droughts of 1982-3 not only shocked the public, but also triggered an interest in the scientific community in the potential role of fire in the humid tropics. Proceeding studies based on carbon-14 dating and soil core excavations provided new evidence that fires had occurred periodically, albeit infrequently, in rainforest ecosystems in Asia, Africa and South- and Central America over the past hundreds and thousands of years (Walsh 1996). These fires often appeared to be associated with human activities (as indicated by the chards of pottery present in the soil) and climatic periods of severe drought events. On a global scale, more frequent and longer drought events associated with anthropogenic-influenced climate change may also exacerbate natural drought events associated with the El Niño oscillation phenomenon, and contribute to increasing the potential for fires occurring in the moist tropics (Beaman et al. 1985, Pyne 1995, McPhaden 1999).

Wild fires became an extraordinary problem in the humid tropics once again in 1998, a year marked by severe droughts associated with the strongest El Nino event experienced over the past 150 years (Neary et al. 1999). Mexico, which is considered to be one of the five most biologically diverse countries in the world (Toledo and Ordóñez 1993), was one of the countries most severely affected by these fires. On a national level in Mexico, there were an estimated 14,445 fires that affected 850,00 hectares. Oaxaca, with 252 million hectares burned, was one of the five states most severely affected by the fires. Eighty-three percent of the area affected by the fires in Oaxaca occurred in the Chimalapas region in the southeast corner of the state (Anta and Plancarte 2000). The Chimalapas region, together with the Lacandona jungle in Chiapas, is one of the most important and best-preserved remnants of tropical rainforest in the country (Rzedowski and Ordóñez 1993). Prior to the intense forest fires of 1998, 463,000 hectares (78% of total Chimalapas area) were considered as well preserved (Salas et al. 1997). More than half of the fires that affected forests in the Chimalapas region in 1998 occurred in primary forest, mostly montane moist forest (for the first time on record) and tropical rain forest ecosystems (Anta and Plancarte 2000).

Fire is intricately linked to human populations – humans directly influence the occurrence and spread of fire, and conversely, fire has important consequences for how communities respond and adapt to their environment. In the Chimalapas region, fire is an important tool used by local people to prepare their agricultural and grazing fields, and many wildfires were caused when these agricultural fires entered into the surrounding forests during an extreme drought year. The unusual and catastrophic fires of 1998 have had significant impacts on local communities, as indicated by subsequent changes in land use activities and in perceptions and management of fire.

The fires of 1998 have also triggered various initiatives by state and national institutions responsible for fire- and disaster-related responses, which have primarily focused on enhancing capacity for fire prevention and control at both the local and regional levels. Two other recognized areas of importance, the restoration of fire-affected areas, and monitoring and evaluation of ecological fire damage and recovery processes, have received substantially less attention. Further, relatively little attention has been given to developing a more thorough understanding of the roots and causes of fire-related problems experienced today, and which are related to more complex interactions between humans and their environment, and the many external political and socioeconomic factors that often drive these interactions. Consequently, restoration proposals and management initiatives following the fires in the Chimalapas region have been based on incomplete ecological and socio-political information about the context in which fires occur, while lacking a broader, integrative framework for enhancing the sustainability of both the natural and human ecosystems in the region. The result has been a lack of clear policies for promoting the recovery and sustainable management of the post-fire landscape in the Chimalapas region, often resulting in unregulated conversion of burned forest areas to other land-use activities, and increased susceptibility of burned forest areas to repeated fires in the future.

The situation in the Chimalapas reflects a general global pattern of paucity of knowledge about the long-term effects of fire and interactions between humans and fire in the humid tropics. Only a few studies have quantified and assessed ecosystem-scale properties such as the flow of nutrients, water, and energy through these systems (Clark 2001), and even fewer have included assessments of the impact of large scale disturbance on these functions (Waide et al. 1998), or their relationship to changes in species diversity and composition (Whitmore and Burslem 1997). Further, studies on fire in tropical moist forests have been largely limited to seasonally dry tropical ecosystems (Kauffman et al. 1993, Miller 1999, but see Nykvist 1996) or fire as part of slash-and-burn agriculture and conversion to pasture for cattle grazing (Miller and Kauffman 1998). More recently, studies have been initiated to enhance understanding of the global impacts of tropical biomass burning (Bazzaz 1998, Cochrane et al. 1999, Still et al. 1999), as well as community-scale issues of species diversity and vegetation change (Pounds et al. 1999,). Research focusing on the social implications and consequences of natural disasters has enhanced understanding of human-environment relations in the context of certain catastrophic environmental events, such as hurricanes (refs) and flooding (refs); however, no studies have explicitly assessed these issues within the context of large-scale fires in the humid tropics – which is a relatively new phenomenon that is only recently being recognized as a serious global threat.

Improving natural resource management planning and designing more effective policies for preventing and managing fire and responding to disaster events requires a sound understanding of the complex interactions between humans and fire, and how these interactions influence decision-making at both the local and regional scales. There is a need for research that explicitly integrates ecosystem-level processes and functions with smaller-scale mechanisms of ecosystem response that explain large-scale patterns and provide indicators for monitoring and predicting ecosystem change. Parallel and closely integrated research is needed to examine the socio-political phenomena that influence the occurrence and spread of fire, and assess the historical context and local knowledge related to the use of fire as an agricultural tool, and the response of local communities to environmental changes resulting from large-scale catastrophic fires. This information is urgently needed to both enhance the reliability of global-scale assessments of the implications of fires in tropical ecosystems for long-term changes in climatic patterns and atmospheric conditions, and to improve the sustainable management of post-fire landscapes in moist tropical regions through appropriate conservation, protection, and ecosystem restoration initiatives.

3. SITE DESCRIPTION

The proposed research site is located in the Chimalapas region of Mexico, situated in the northeastern corner of the State of Oaxaca, in the heart of the Isthmus of Tehuantepec, which is the narrowest portion of the country between the Pacific Ocean and the Gulf of Mexico. The Chimalapas region is recognized as one of the most important and best-preserved remnants of tropical rain forest in Mesoamerica, together with the adjacent Lacandona region in the State of Chiapas (Rzedowski and Ordóñez 1993). The IUCN has recently proposed the Chimalapas region as a priority conservation site and recommended the establishment of a protected area (IUCN, 1990).

3.1. Biophysical context

The two municipalities that form the Chimalapas region, Santa María Chimalapa and San Miguel Chimalapa, together encompass an area of 594,000 hectares (460,000 ha and 134,000 ha, respectively). The region is characterized by great variation in altitude, topography, and climate, with elevation varying between 200 to 2,500 m.a.s.l., and the range of mean average annual precipitation estimated at 700 to 3,000 mm/yr. Prior to the extensive forest fires of 1998, 463,000 hectares (78% of the total Chimalapas area) were considered as well preserved, of which 48% was in humid tropical evergreen forest, 14% in tropical semi-deciduous forest, and 13.5% in tropical montane cloud forest (Salas 1998). Over the last 30 years, deforestation, ecological degradation, and habitat fragmentation have, according to studies by SERBO, SEMARNAP and WWF, contributed to the loss or severe disturbance of more than 300,000 hectares of forest cover in the Chimalapas (Milenio, 28 September 2000), and continue to pose serious threats to region's remaining forests. These studies also indicated that prior to the 1998 fires, an estimated 60% of the lowland deciduous forests was severely fragmented, while approximately 20% of the tropical montane cloud forest ecosystem was highly fragmented. The fires of 1998 affected an additional 126,000 ha of the region's remaining primary forest cover.

Complex interactions between the mountainous topography and variable climate within the Chimalapas region contribute to the existence of a wide range of different ecosystems and microclimates that support a high diversity in flora and fauna, represented by unique associations between Holarctic and Neotropical elements. The exceptionally high degree of endemism found in the region has been attributed to both its high habitat variation and its position in the transitional zone between temperate and tropical climates, which likely enabled the region to serve as a refuge for sensitive species during prolonged glacial events (Toledo 1988, Rzedowski 1992, Wendt 1989, 1993). Floristic surveys indicate that the Chimalapas region provides a habitat for 25 threatened species, 3 rare species, 7 species in danger of extinction, and 4 species having special protection status (e.g., *Cordia alliodora, Switenia macrophylla, Chamaedorea ernesti-angusti, C. metallica* and *Pinus chapensis*). Among the fauna, 22 species are endangered, 47 are threatened, 9 have special protection status, and a total of 57 species are included in the CITES list of endangered and threatened species (e.g., *Odocoilleus virginatus, Tamandua mexicana, Nasua narica, Lontra longicaudis, Leopardus pardalis, Leopardus weidii, Cocrodylus moreletii, Iguana iguana, Boa constrictor*). Of a total of 51 fish species registered for the Chimalapas, 9 are endemic, 4 are in danger of extinction, and 1 is threatened (Salas et al. 1997).

In the Chimalapas region, high biological diversity translates into high ecosystem diversity, as reflected by the nine distinct vegetation types occurring within the landscape mosaic: upper montane wet evergreen forest, lower montane wet evergreen forest, montane cloud forest, pine forest, oak-pine forest, oak forest, tropical deciduous forest, elfin forest, and chaparrera (prehispanic secondary forest) (Salas et al. 1997). Of these ecosystems, tropical montane cloud forest is considered to be one of the most threatened ecosystems on a global scale (Hamilton et al. 1995), and in danger of extinction in Mexico (Cárdenas Hernández et al 1994, Bubb 1991). Although cloud forests comprise less than 1% of the total area in Mexico, these ecosystems encompass approximately 10-12% of the total diversity of flora in the country, and possess a degree of endemism of

30% at the species level, reaching 73% for epiphytic plants (Gentry 1982, Challenger 1998). Only about 10-15% of the original cover of moist tropical evergreen forests are estimated to remain in Mexico today, coinciding with approximately 2.9 million hectares, of which Oaxaca, together with Campeche, Quintana Roo, and Veracruz still maintain important remnants of this vegetation type (Challenger 1998). These ecosystems are among the most diverse in Mexico, reaching up to 267 species per hectare of which approximately 160 are tree species (Meave 1983 p317).

The cloud forest ecosystems, together with the lower elevation evergreen rainforests, play an especially important role in regulating key ecological functions in the region. These ecosystems receive a proportionately greater amount of the total precipitation entering the region, due to both higher rainfall and, in the case of cloud forest, the large quantities of cloud water captured by the vegetation. The headwaters of the four major rivers in the region (the Catzacoalcos and Uxpanapa rivers flowing to the Gulf of Mexico, and the La Blanca and Osruta rivers flowing to the Pacific) are located in the Chimalapas mountains, and are therefore important for generating water to downstream ecosystems and human populations located in drier climatic zones, as well as regulating hydrological cycles on the landscape scale. Further, the region provides the high watershed for four of the most important hydrological regions in Mexico (Costa de Oaxaca-Tehuantepec, Costa de Chiapas, Coatzacalcos-Tonalá and Grijalva-Usumacinta). The important ecological functions provided by these forests are directly dependent on maintaining healthy and sustainable ecosystems and local communities. However, the fires of 1998 affected approximately 38,000 ha of a total of 67,244 ha (57%) of montane cloud forest in the region, of which 12,000 ha consisted of high severity crown and ground fires (Garnica-Sanchez y Gomez-Vieros, 1999).

Growing pressures on the resources in the Chimalapas region has led to increasing habitat fragmentation and ecosystem conversion. In particular, the illegal extraction of timber and the invasion of lands by large-scale cattle ranchers have escalated the intensity and extent by which the forests are being altered (Cardenas 1994, Garcia et al. 1995). An estimated 60% of the lowland deciduous forests are severely fragmented, while approximately 20% of the tropical montane cloud forest ecosystem is highly fragmented (Schibli 1997), although these figures have likely increased significantly since the fires of 1998. Previous ecological surveys/studies in the Chimalapas region were primarily concerned with documenting the distribution of plant associations and species diversity, with very little attention given to ecosystem processes and functions such as nutrient cycling, productivity and disturbance dynamics.

3.2. Socioeconomic context

According to the 2000 National Census, 12,890 people live in the Chimalapas region and are distributed in 34 communities, many of which have a population of 100 people or less. The region is home to 7 different ethnic groups (Zapoteco, Chatino, Mixteco, Chinanteco, Tzotzil, Tzeltal, Zoque), as well as to Mestizos arriving from Veracruz, Michoacán, Guerrero, Durango, Zacatecas, among other states (Anaya et al. 1994). As in other highly marginalized regions of the country, the annual population growth rate in the region is high (2.7%), significantly exceeding the state average of 1.3%. The region is characterized by poor infrastructure and public services, while lack of institutional support for production and commercialization have intensified the region's socioeconomic isolation. The high degree of poverty is further reflected by the high incidence of malnutrition, curable diseases, illiteracy, and mortality (Beltrán 1999).

Most of the land in the Chimalapas region is managed through the traditional scheme of communal land tenure, which includes a series of institutions and decision-making processes for governing the commons, all of them legally recognized in the Mexican laws at the Federal and State levels. Small-scale subsistence agriculture, based on traditional techniques for maintaining the "milpa" (an integrated maize-beans-squash system) continues to be an important component of the local family economy. However, driving forces behind land use change are increasing the irrational exploitation of timber and non-timber forest resources and the expansion of extensive cattle ranching. Extraction of precious and semi-precious tropical hardwoods and pine timber is promoted by a network of intermediaries and external groups maintaining strong interests in the region. Similarly, livestock production, predominantly financed by large cattle owners, presents another important mechanism for quick financial return, while contributing little to long-term ecological, social, and economic sustainability in the region. Both of these activities, together with others that are more difficult to register, (e.g., trade in plants and wildlife, hunting, fishing, and narcotics production), comprise the dominant pattern of productive activities, and cause environmental and social impacts that are ecologically unsustainable and socially disadvantageous for the local peasant population. In addition, these processes have eroded the capacity of local community institutions to regulate the access to their natural resources, despite legal recognition at the state level of indigenous peoples' rights and authorities. This has created a complex social situation, where external initiatives to promote sustainable development, both from the governmental and non-governmental sectors, are regarded with a high degree of suspicion and no confidence.

3.3. Characteristics of the target vegetation types

Moist tropical evergreen forest (*"selva alta perennifolia")* is geographically limited by temperature and precipitation. Mean annual temperature ranges between 20-26 °C and minimum temperature, never falling below 0 °C (Rzedowski 1978). Annual mean precipitation ranges between 1,500 and 3,000, although it may exceed 4,000 in some areas, with a notable degree of seasonality in which rains are relatively scarce during three month of the year. Altitudinal range is generally between 0-1000 msnm, which coincides with the minimum temperature isotherm of 0 °C. The high and relatively constant temperature and humidity in these ecosystems allow for the growth of exuberant vegetation supporting what is often described as up to six different strata of vegetation (i.e., herbaceous, shrub, two sub-canopy strata at 3-14m and 15-22m, the canopy strata with lianas and epiphytes (30-40 m), and a strata of isolated emmergents with 40-50 m trees (p320 Challenger 1998). Moist tropical semi-deciduous rainforest *("selva mediana")*, in which 25-50% of the trees lose their leaves, occurs under similar climatic conditions as tropical evergreen rainforest, but sites with shallow or highly well-drained soils. This forest type also occurs where the dry season is longer (3-5 months) (c.f. Challenger 1998).

Tropical montane cloud forest is restricted to narrow altitudinal zones in mountain regions maintaining frequent cloud cover at the level of the vegetation as a result of orographic condensation of moisture-saturated air masses originating over the ocean.

Consequently, this zone is characterized by high precipitation and atmospheric humidity throughout the entire year (Hamilton et al., 1995, Challenger 1998 p 468). Cloud forest ecosystems grow in colder climates than those required by moist tropical evergreen forest. Typically cloud forest occurs in Mexico between 600-1,000 msnm. The lack of meteorological stations in this ecosystem type in Mexico allows for only general estimations of climate for this zone. Mean annual temperature may very between 12-23 °C, dropping to below 0 °C and accompanied by frosts during the winter. Mean annual precipitation is typically around 2,000 mm, but may reach up to 5,000-6,000 mm in some areas (Rzedowski 1978). "Horizontal precipitation" in the form of water captured by the vegetation from the clouds represents a significant yet difficult to quantify ecological factor in these forests. The structure of cloud forest in Mexico is similar to that described for moist tropical evergreen rainforest, although often with fewer evident strata and less exuberant and dense vegetation, and tree height decreasing with increasing elevation and steepness of slope.

Cloud forests are botanically unique ecosystems, combining elements of both holarctic and tropical origin, with the former most prominent among the canopy species and the latter having greater abundance in the understory (Carlson 1954, Challenger1998). Some authors consider that these ecosystems are ancient communities that have undergone contractions and expansions in their distribution during different geologic time periods, and that this phenomenon in conjunction with its fragmented distribution, has resulted in important processes of speciation, which determine the presence of various families having a high degree of endemic species (Rzedowski and Palacios-Chávez 1977, Toledo 1982). Although cloud forests comprise less than 1% of the total area in Mexico, these ecosystems encompass approximately 10-12% of the total diversity of flora in the country, with between 2,500-3,000 plant species found predominantly or exclusively in its habitat (Challenger 1998). The degree of endemism at the species level has been estimated at around 30%, while 73% of the epiphytic and "palmettos" are endemic (Gentry 1982, Challenger 1998). Tropical montane cloud forests are particularly fragile ecosystems because their persistence is strongly dependent upon the microclimate maintained by the forest itself, and when the vegetation is destroyed is often replaced by pines (Challenger 1998). Mexican cloud forests are considered as ecosystems in danger of extinction (Cárdenas Hernández et al, 1994, Bubb, 1991, Challenger 1998), and on a global lever they are also one of the most threatened ecosystems (Hamilton et al., 1995). An estimated 40-50% of the original cover of cloud forest in Mexico has already been lost (Toledo et al. 1 989)., with approximately 8,000 km2 remaining (Challenger 1998). On exposed ridges in the highest elevations, a unique vegetation association of dwarf-sized evergreen trees and shrubs referred to as "elfin forest" develops above the zone of the cloud forests where the wind, cold, and other factors prevent the growth of tall forests (Challenger 1998).

3.4. The fires of 1998 in the Chimalapas

The severity of the fires of 1998 on the forest ecosystems in the Chimalapas were roughly characterized according to three different categories: (1) surface fires – which primarily affected the surface litter layer and caused minimal damage to the living vegetation, (2) ground (subterranean) fires – which penetrated into the surface organic matter layer and affected the rooting system, often causing eventual death of the aboveground vegetation, and (3) crown fires – which reached the canopy of the forest, killing most trees in the affected area, and representing the most severe type of fire (Garnica-Sanchez 2000). An estimated 210 million hectares were affected by the fires, of which 63% were superficial fires, 25% were subterranean fires, and 12% were crown fires. Of the affected area, 82% occurred in the municipality of Santa María Chimalapa, and the remaining in the municipality of San Miguel Chimalapa. The surveillance flights also indicated that several regions (i.e., Cerro Azul, El Tapanero, and Río El Corte) were completely removed of the forest cover, and are affected with severe overland erosion and soil loss (Anta and Plancarte 2000).

The occurrence of these different types of fire was highly variable within the landscape, determined by complex interactions between different influencing factors such as topography, changes in wind direction and speed, climatic conditions, vegetation type, and fuel quantity and status. Consequently, the post-fire landscape represents a patchy mosaic of differentially burned areas interspersed with non-affected vegetation sites. Further, the fires occurring in the Chimalapas region in 1998 were unique from previous fires in the region or in other moist tropical forests in the world in that many of these fires were initiated from within a contiguous forest system. This is a very different process from the typical pattern where fires are restricted to the periphery zones of vegetation cover, and are extinguished prior to reaching more distant interior forest zones. The particular characteristics of the fires in the Chimalapas region pose important questions both for basic and applied research in terms of understanding the recovery processes of relatively undisturbed and intact forest ecosystems after burning. Further, the ecological consequences of such an extensive disturbance in cloud forest and tropical moist forest are largely unknown on a global basis.

The patterns of damage caused by the 1998 fires in the Chimalapas (i.e., location, extent and intensity) have been documented on a landscape scale by consulting maps produced based on the result of an analysis of satellite images and aerial photos conducted by SERBO, A.C. Of the nine different vegetation types occurring in the Chimalapas region (see above), three were identified as priority sites for this research: tropical moist evergreen forest, tropical montane cloud forest, and elfin forest. This selection was based primarily on their global importance, the lack of knowledge on a national and global scale about the recovery processes and mechanisms of these forest types in response to fire, and finally their critical importance for the sustainability of the biodiversity and ecosystem functions within the Chimalapas landscape. Based on the information obtained about landscape patterns of fire damage in relation to the priority vegetation types in the region, two key zones were identified as priority project sites: (1) the tropical montane cloud forests occurring in the eastern zone of San Miguel Chimalapas and Santa María Chimalapa (near the communities of Benito Juárez, San Antonio, and Nuevo San Juan), and (2) the tropical evergreen moist forests in the north-western zone of Santa María Chimalapa (near the communities of Santa María and Chalchijapa).

Estimates of the total area of influence and fire-affected area for each community, according to fire severity and ecosystem type, is presented in the table below:

Community	Area of Influence	Fire-affected area	Fire severity	Geographic coordinates
Benito Juárez	15,000	12,000	Surface: 9,000 (pine-oak forest) Ground: 1,800 (cloud forest) Crown: 1,200 (pine-oakforest)	16 40 – 16 44' N 94 03' – 94 12' W
San Antonio	25,000	17,000	Surface: 12,750 Ground: 3,400 (cloud/elfin forest) Crown: 900 (elfin, cloud, pine-oak)	16 35' – 16 43' N 94 04' – 94 20' W
Santa María	45,000	23,000	Surface: 13,800 (rainforest) Ground: 8,500 (rainforest) Crown: 700 (rainforest)	16 44' = 16 17' N 94 27' – 94 45' W
Chalchijapa	16,000	8,000	Surface: 5,600 (rainforest) Ground: 2,200 (rainforest) Crown: 200 (rainforest)	17 00' – 17 05' N 94 33' – 94 42' W
Nuevo San Juan	20,000	14,000	Surface: 8,400 (pine-oak forest) Ground: 4,900 (cloud forest) Crown: 700 (cloud forest)	16 50' – 16 55' N 94 05' – 94 15' W

** source: Preliminary evaluation maps of the forest fires. 1998. SEMARNAP, Maderas del Pueblo del Sur-Este A.C., and SERBO, A.C.*

3.5. Observations on patterns of fire damage in cloud forest

Initial field observations following the 1998 fires in the Chimalapas region were conducted in cloud forests affected by the fires in the western region of San Miguel Chimalapa approximately one and two years following the fires, and more extensive survey conduced in the same region during the period April-July 2001. No observations have yet been made in tropical moist lowland forests affected by the fires in Santa María Chimalapa.

Fire severity was observed to vary strongly according multiple factors, including aspect, elevation, vegetation type, soil type, and topographical position. The patterns observed suggested an overall relationship between fire severity and moisture conditions, which is further translated into differences in ecosystem productivity as reflected roughly by mean tree height of the overstory canopy. Sites having high ecosystem productivity (cloud forest with trees averaging 20-25 m) tended to be located on more moist sites (valleys and lower slopes) with well developed mineral soils, and when affected by fire, burn severity was usually low to moderate (surface fires and ground fires), with a high degree of patchiness due to non-burned areas mixed in with areas having different burn severities. Sites supporting moderate ecosystem productivity (cloud forest with trees averaging 15-20 m) were generally located on mid- and upper slopes, often on mixed mineral soils have a strong karst component, and fires were often ground fires that eventually resulted in the mortality of the majority of the mature canopy trees. Finally, low productive sites (elfin cloud forest with trees averaging 6-10 m) and restricted primarily to highly exposed ridge tops and plateaus, and located on karst topography, were completely burned by crown fire, resulting in total mortality of almost all the vegetation and consumption of the organic soils and exposure of the underlying karst substrate. No unburned elfin forests could be located during the field visits, although an apparently unburned site located approximately – km from our point of observation was identified, and later confirmed by consulting satellite images of the post-fire landscape.

Current stages of plant regeneration and ecosystem recovery were observed to vary according to the burn severities and vegetation types mentioned above. Despite the generally large-scale mortality of mature species in areas affected by ground fire, particular species (i.e., *Quercus, Pinus, Podocarpus, Cypruss)* were often found to survive. *Quercus and Pinus* are known to have a high capacity to resist disturbance due to special physiological adaptations (Abrams 1990, Barton 1993). The presence of these live trees in fire-affected forests likely has important implications for post-fire ecosystem recovery processes through amelioration of microclimate by providing shade and protection, reducing soil erosion, and production of seed for regeneration of new individuals. The exceptionally high mortality of mature trees observed in the Chimalapas forests in contrary to that reported in the literature for other tropical moist forests, where approximately 95% of stems <1 cm dbh (i.e., small seedlings) are killed, while less than 45% of trees over 20 cm dbh are killed (Cochrane et al. 1999).

Particular species also showed a high propensity for establishing as seedlings following fire. After only one year following the fires of 1998, seedlings of both *Quercus* and *Pinus* were observed establishing in the fire-affected montane tropical cloud forest. The genera *Quercus* and *Pinus* typically have ecological adaptations that enable them to regenerate rapidly following a disturbance, such as vegetative regeneration from stump sprouts (oaks) and serotinous cones that survive fire and release their seed afterwards (Abrams 1990, Barton 1993). However, it mechanisms operate in pine and oak species occurring in the Chimalapas region. Only a few tropical species (i.e., Podocarpus, Cypruss, Cedrella) were observed as seedlings following the fire. However, it is not yet clear whether the observed seedlings established from seed, sprouting, or root suckering. The overall low density of mature canopy seedlings suggests that the forest ecosystems have been "set back" by the fires to an earlier successional stage, and will likely pass through a series of changes in vegetation structure and composition before mature cloud forest ecosystems can potentially be re-established. Studies on seedling regeneration following large-scale fire in moist tropical forests in other regions of the world also indicate that the post-fire forests are generally succeeded by species not belonging to the mature forest guild (Uhl and Jordan 1984).

In contrast to the cloud forest ecosystems, elfin forests did not support any new seedlings following the fires, and were dominated by a sparse cover of annual herbs and graminoids. The lack of mineral soil on these sites will likely pose a major barrier to the reestablishment of vegetation, resulting in a much slower process of recovery of structure and function in these ecosystems.

Despite the general lack of tree seedlings in post-fire cloud forest, other plants were observed to be re-establishing during the two years following the fires. One of the most common early successional plants was fern, which is capable of spreading rapidly in an area through vegetative growth via rhizomes. The ferns may either have arrived to the burned site as spores carried by wind, water, or animals, or they may have existed on the site prior to the fire and survived as rhizomes below the ground in cases where the fire did not penetrate the soil horizon too deeply. Two herbaceous plant species that regenerate vegetatively via rhizomes ("Congera" (local name) and a species from the genera *Phytolacca*) were also observed rapidly invading fire-affected areas where the forest canopy had been largely removed. While ferns and herbaceous plants tended to dominate on more severely burned sites, areas affected by less intense fires supported a more dense vegetation of early succession trees, shrubs, and vines. The particular ecological characteristics and adaptive strategies of the various species establishing on sites affected by different severities of fire will strongly influence the recovery patterns and processes of the forest through two key mechanisms: (1) facilatory effects and site amelioration – through the uptake and conservation of nutrients and moisture, moderating effects on microclimate (i.e., temperature, wind, radiation), and providing habitat for seed dispersers of other plant species; and (2) competition and inhibitory effects – through the occupation of available space and monopolization of resources.

Different life forms were also observed to respond differently to fire within the cloud forest ecosystems, representing another potentially important contribution to the regeneration and recovery process. In particular, epiphytes appeared to have a high capacity to survive fire, and in even completely defoliated canopies they often remained as green and seemingly healthy components of the otherwise denuded canopy (pers. obs.). As mentioned earlier, epiphytes (including bromeliads, orchids, and bryophytes) are predominant elements of tropical montane cloud forests, and are particularly important in nutrient cycling and ecosystem productivity. Thus, their continued presence in post-fire forests may serve as an important mechanism for retaining nutrients in the system. Their high propensity for survival may be due to the fact that the fires did not affect the forest canopy and cause direct damage to the epiphytic tissues. Further, canopy soils and plants are continuously subjected to changing cloud cover and wind conditions and therefore organisms living in the canopy must be particularly well adapted to extremes in temperature and moisture as compared to those habiting the forest floor. For example, the canopy humus in a TMCF in Costa Rica experienced periods of rapid and severe dehydration (20-40% of water content), while the forest maintained a consistently high water content (60-70%) (Nadkarni et al. 2000). Adaptations of epiphytes to extreme environmental conditions may have provided an advantage for surviving the changes imposed upon the ecosystems by the fires.

One of the most conspicuous elements observed in the post-fire landscape the first year after the fires of 1998 was the large number of dead standing trees. During the second year an additional pronounced factor was evident: the sound of falling trees crashing to the ground in the distance in different directions within the burned forests. As mentioned earlier, in the more severely burned sites and on steep slopes, much of the surface litter layer and organic soil horizon had been removed either directly by the fires, or through erosion processes following the fires. As a result, both live and dead trees often remained with the root systems exposed above the ground, and highly vulnerable to toppling from wind or other disturbances. The sight and sound of dead wood was just one important indication of the significant increase in the amount of highly combustible material in the forests. Other factors include the changed climatic conditions due to the open canopy and lack of vegetation, resulting in elevated temperatures, reduced air and soil humidity, and greater exposure to wind, all of which may lead to drying out of the large quantities of dead woody material in the forests. The result: large expanses of burned tropical moist forest that are highly susceptible to repeated fires if another drought year occurs, and if adequate management precautions are not set into place. However, it is also important to recognize that the susceptibility of a particular site to future disturbance also varies according to both the pre-fire and post-fire conditions on the site. More severely burned areas in terms of fire intensity and the size of the area affected are likely to have a greater chance of ignition by fire than less severely burned sites. Indicators such as the degree of tree mortality, the depth of the litter layer and soil horizon burned, and the amount of dead wood on the forest floor may provide a measure of the risk of fire at a particular site.

4. METODOLOGÍA DE LOS ESTUDIOS PRELIMINARES

Here we present the results of preliminary studies conducted for fire-affected cloud forect ecosystems located in the communities of Benito Juárez and San Antonio, hich represent the focus of this research effort up to the current date.

4.1. Selección de los sitios y ubicación de las parcelas

En el poblado de San Antonio seleccionamos siete sitios de estudio, la mayoría de ellos ya habian sido visitados en ocasiones anteriores, mientras que en Benito Juárez elegimos tres sitios, dosde los cuales fueron integrados por primera vez al estudio. Los criterios que utilizamos en la selección de los nuevos sitios fueron: tamaño adecuado para la instalación de los cuadros de trabajo, tanto en la zona conservada como la zona quemada; semejanza entre las áreas quemadas y los controles (área conservada), en cuanto a su relieve, exposición, pendiente, altitud y tipo de vegetación. En los dos casos procuramos que el área quemada estuviera contigua al área conservada.

Ubicamos parcelas de 30x30 m en los sitios de estudio, considerando la forma y el tamaño del sitio, la dirección los cuadros se estableció con ayuda de una brújula (SILVA, Ranger). Las parcelas fueron separadas de las zonas de contacto (borde entre el área quemada y conservada) por una distancia mínima de 15 m, con el propósito de reducir el efecto de borde, aunque en el caso del sitio 2 y 4 de San Antonio uno de los lados de los cuadros quedo a una distancia de 10 m.

4.2. Caracterización física de los sitios.

Todos los sitios fueron gereferenciados (GPS, Garmin), tanto en el área quemada como en la conservada, excepto en el caso de la parcela conservada del sitio 3 en Benito Juárez donde el GPS no capto la señal de los satélites. En cada sitio medimos la altitud (Altimetro, Suunto), pendiente (Clinometro, Shunto PM-566P), exposición (brújula, SILVA, Ranger). Además se hizo un pozo para describir de manera general las siguientes variables edáficas: grosores de hojarasca, humus, fase orgánica, fase mineral, profundidad de raíces finas y porcentaje de raíces finas. En la mayor parte de los pozos realizados no se llego a la profundidad en que se encuentra la roca madre.

4.3. Variables estructurales.

En cada cuadro medimos el área basal del sitio, tomando una lectura en centro del cuadro con ayuda de un relascopio Spiegel (102151); para evaluar la altura media de dosel, medimos la altura de 5 individuos con un clinometro (Suunto), considerando los árboles más altos y comunes del dosel de la comunidad. El porcentaje de densidad de cobertura fue evaluado con un densiometro esférico (modelo-A), se tomaron 4 lecturas con el densiometro dentro del cuadro, una lectura en el centro de los cuatro subcuadros de 15x15 m en los que se dividió el cuadro principal, se promediaron las lecturas y se obtuvo la densidad de cobertura promedio de la parcela, esta actividad solo se realizo en las parcelas conservadas.

Las variables estructurales y fisicas consideradas fueron analizadas considerando de manera independiente a las parcelas conservadas y quemadas, a través de análisis de varianza y una prueba pareada de Tukey- Kramer HSD, con el propósito de identificar las diferencias entre sitios y comprobar el diseño original del proyecto (en lo relacionado a los grupos de productividad, alta, media y baja).

4.4. Colecta y determinación taxonómica de la flora

El trabajo de colecta del material botánico se ha realizado en los bosques húmedos de montaña de las congregaciones de San Antonio y Benito Juárez, principalmente dentro de las parcelas (cada una de 600 m2) donde se llevará a cabo el estudio y monitoreo de los efectos de los incendios de 1998.

La colecta del material se realizó durante un mes de trabajo de campo que abarcó dos épocas del año; el final de la temporada seca (meses de marzo-abril) y el inicio de la temporada de lluvias (julio). Hasta este momento se han visitado alrededor de 10 localidades distintas cada una de ellas involucrando dos tipos de parcelas, una afectada por los incendios y otra de bosque original no afectada por éstos.

Los ejemplares colectados provienen de individuos fértiles ubicados dentro de las parcelas de estudio. De cada individuo se han herborizado de tres a cinco muestras, que consisten en pedazos de ramas con flor y/o fruto no mayores de 50 cm que se colocan en hojas de papel periódico para realizar su prensado. Sólo en el caso de las hierbas las muestras pueden corresponder a individuos completos y de mayor talla. En campo el material ha sido prensado entre hojas de papel periódico y se ha humedecido con alcohol al 50% y colocado en bolsas de plástico selladas para realizar su traslado. Esta técnica nos ha permitido mantener el material colectado en buenas condiciones por largos periódos de tiempo antes de ser secado. El material se ha prensado por el metodo tradicional con prensas botánicas que presionan el material entre hojas de papel periódico y cartón y se ha secado con un ventilador de aire caliente por un lapso de dos días. Finalmente a cada ejemplar se le han colocado sus etiquetas de colecta en las que se anota toda la información de campo asociada a él: localidad de colecta, coordenadas geográficas, altitud, fecha de colecta, colector, descripición del hábitat y del ejemplar (forma de crecimiento, tamaño, descripción de la flor y/o fruto), nombre común y usos.

Finalmente el material ha sido trasladado al herbario del Instituto Politécnico Nacional sede en Oaxaca (CIIDIR) para su determinación taxonómica, la cual se realiza mediante el uso de floras, claves, y monografías. El material será cotejado con los ejemplares de la colección del Herbario Nacional de México (MEXU). Las especies problemáticas serán revisadas en el Missouri Botanical Garden en fechas próximas.

5. RESULTADOS PRELIMINARES

5.1. Descripción física de los sitios de estudio

Los resultados de la ubicación geográfica, de las características topográficas y las edafológicas de los sitios de San Antonio y Benito Juárez se encuentran en las tablas 1 y 2.

En San Antonio los sitios se ubicaron entre las latitudes que van de los 16° 39’ 51.7’’ N a los 16°42’40.8 N y entre las longitudes de 94°13’57.3’’ a 94°16’49.0’’ W. El intervalo altitudinal, en que se distribuyen los sitios de estudio quedo ubicado entre los 1640 m y los 1840 m s. n. m.; la separación altitudinal entre las parcelas conservadas y las quemadas es entre 5 y 20 m en la mayor parte los de los sitios, excepto en el sitio 1 donde existe una diferencia de 150 m (Tabla 1). Cinco sitios fueron ubicados en laderas con exposiciones SW (1, 2, 4, 6), exposición W (sitios 2, 4 y 6) y SE el Retén; los dos sitios restantes, el 3 y el 5, fueron ubicados en zonas planas con una exposición NW. Las pendientes de las parcelas fueron en general de ligeras a moderas en 5 sitios (3°-17°; sitios 2, 3, 5, 6 y Retén), sólo en lo sitios 1 y 4 las pendientes fueron más pronunciadas (26°-30° y 23°-25°, respectivamente).

Los tres sitios de estudio ubicados en la congregación de Benito Juárez se encuentran localizados entre las siguientes coordenadas 16°44’02.0’’N - 16°44’30.1’’N y 94°11’30.2’’W – 94°11’45.9’’W. El intervalo altitudinal en el que se ubican los sitios es de 140 m, entre los 1585 m a los 1725 m s. n. m. Las parcelas de estudio de los tres sitios están ubicados en laderas que presentan pendientes moderadas en el sitio N 1 y altas en los sitios 2 y 3 (Tabla 2), La exposición de las parcelas del sitio 1 es al W, las de l sitio 2 al N y en caso de las parcelas del sitio 3 se presentan dos exposiciones N y S, ya que quedaron ubicadas en sitios de filo de montaña.

5.2. Descripción de la vegetación: composición y diversidad

Las siguientes observaciones son el resultado de varias semanas de trabajo realizado en abril, mayo y julio de 2001. Se visitaron principalmente las áreas afectadas por los incendios de 1998 en la zona oriente del municipio de San Miguel Chimalapa como parte de la planeación del proyecto “Monitoreo y evaluación de los impactos de los incendios de 1998 en Chimalapas, Oaxaca”.

5.2.1. Vegetación de montaña

Las comunidades vegetales que predominan en las zonas montañosas del trópico húmedo se caracterizan por una compleja estructura que varía de acuerdo a las distintas condiciones físicas y ambientales que se desarrollan en un gradiente altitudinal amplio; donde además de encontrar variaciones en los parámetros de temperatura y humedad, cambian la topografía y en ocasiones también la geología y el tipo de suelo. Asociado a esta variación estructural de las comunidades, se genera un recambio de especies por piso altitudinal y por lo tanto un aumento en la riqueza especifíca para la región. Por lo anterior, es común considerar a estas comunidades húmedas de montaña como sitios importantes de biodiversidad.

Está variación estructural de las comunidades vegetales dentro de amplios gradientes altitudinales parece tener una correspondencia con cambios entre asociaciones taxonómicas a niveles altos (familias y géneros) en los pisos altitudinales de distintas regiones. Así mismo, algunos autores han propuesto el desarrollo de una nomenclatura que corresponde con los cambios de estructura que se suceden unos tras otros en las montañas y que corresponden al premontane pluvial forest (tropical lowland evergreen), lower montane pluvial forest (cloud forest), y upper montane pluvial forest (pine-oak forest). Así mismo, se dan variantes asociadas a condiciones más particulares de topografía o condiciones de exposición directa a los vientos como sucede con los bosques enanos o elfin forests cuyo componente epífito es abundante.

Estas características de complejidad estructural y de riqueza de especies se repiten en las comunidades vegetales que se desarrollan en la zona montañosa de la región de los Chimalapas. Sin embargo, es importante resaltar que la variación en estos bosques no se encuentra asociado a un gradiente altitudinal amplio sino por el contrario estos cambios se desarrollan entre un intervalo de no más de 400 m de altitud, dentro de lo que corresponde de uno a dos de estos pisos altitudinales.

5.2.2. Variación estructural del bosque

En la zona de San Antonio y Benito Juárez la variación estructural está principalmente determinada por el tipo de geología que corresponde a rocas calizas y metamórficas, así como por la variada topografía que determina distintos tipos de pendiente y de exposición. En general, estos bosques se desarrollan sobre un gradiente no mayor de 300 m que va de los 1585 a los 1840 m s.n.m. Sin embargo, es interesante resaltar que a pesar de que este gradiente no es muy amplio para marcar cambios importantes en variaciones de temperatura y humedad, su variada topografía detemina distintas condiciones microambientales que se relacionan con planicies, laderas o cauces de arroyos.

Durante nuestras primeras observaciones en los bosques asociados a sustrato kárstico (en San Antonio) se han detectado tres variantes de bosque, que estructuralmente corresponden a bosques con árboles altos (mayores de 25m), medianos (de 15 a 25 m) y bajos (de 5 a 15 m). Así mismo, asociado a la altura de los árboles la biomasa estimada como el promedio de área basal varía por tipo de bosques presentando intervalos que van de los 6 m^2 a los 36 m^2 de área basal. En Benito Juárez, por el contrario los bosques asociados a sustrato metamórfico parecen tener variaciones estructurales menos marcadas. Además, los sitios con grandes cambios estructurales parecen haber desaparecido totalmente con los incendios de 1998, pues la vegetación de Cerro Salomón descrita como selva baja perennifolia (Ishiki, 19xx) o elfin forest ya no existe. Hasta este momento podemos decir que los sitios de baja productividad se encuentran asociados a lugares con alta exposición al viento que corresponde a los filos de las montañas y a algunos montículos que quedan directamente expuestos a ellos. Por su parte, los de productividad media se desarrollan sobre las partes altas de las laderas y los de productividad alta sobre las partes bajas de las laderas, sitios relativamente planos y/o arroyos.

5.2.3. Variación florística del bosque

Desde el punto de vista florístico son comunidades con una alta riqueza específica, y mediante colectas sistemáticas podremos en un futuro determinar las variaciones en términos de composición de especies que presenta las distintas comunidades que integran estos bosques. Sin embargo, es importante mencionar que guardan similitudes florísticas típicas con los bosques húmedos de montaña de otras regiones, muestra de estas semejanzas son los representantes de las familias Lauraceae, Fagaceae, Rosaceae dentro de los estratos árboreos altos; Rubiaceae, Myrsinanceae, Theaceae, Araliaceae y Melastomataceae en los estratos medios y bajos. Algunos géneros importantes que se han detectado como elementos dominantes de estos bosques son *Liquidambar styraciflua, Ticodendron incognitum*, *Matayba oppositifolium*, *Quercus* spp., *Podocarpus* sp., *Magnolia* sp. y *Coccoloba* sp. Con respecto al estrato herbáceo tanto el terrestre como el epífito presentan una gran diversificación en grupos como: orquídeas, bromelias, helechos y aráceas. Cabe resaltar que en los bosques de San Antonio existe una alta diversificación del género *Chamaedorea* (alrededor de 8 especies), cuyas amplias poblaciones han permitido durante décadas ser consideradas como un recurso importante para el sustento económico de varias familias de “palmeros”.

Una característica que llama la atención de los bosques de Los Chimalapas es la abundante presencia de especies que corresponden a familias típicas de selvas húmedas de tierras bajas como serían el caso de los géneros *Ficus* y *Trophis* dentro de las Moraceae, *Inga* en Fabaceae y *Cedrela* dentro de Meliaceae. Varias de ellas guardan un papel importante por su abundancia y en ocasiones son el elemento más conspicuo por las enormes tallas que desarrollan. La presencia de estos elementos, típicos de tierras bajas, nos señala que los bosques estudiados correspondan a una zona de transición entre la vegetación típica de zonas bajas y la de tierras altas, característica que permite tener una riqueza específica sobresaliente. Es probable que estos bosques queden delimitados en el esquema de Holdridge como premontane rain forest, sin embargo es necesario completar la determinación taxonómica de la mayor parte de sus componentes para tener conclusiones más claras.

El entendimiento detallado de la riqueza específica de los bosques no dañados permitirá entender el grado de daños ocasionados por los incendios y comprender los procesos sucesionales presentes y futuros. Lo anterior permitirá fortalecer su desarrollo y manejo a partir de la sociabilización de la información con los pobladores de la región.

5.2.4. Comunidades vegetales incendiadas

Los sitios incendiados también muestran variaciones estructurales que pueden ser equiparadas con las encontradas para los sitios no quemados. Hasta el momento se han hecho colectas generales de las plantas que sobreviven en estos sitios y se han medido las condiciones promedio en que se encuentra el estrato árboreo. En general, en todas las parcelas se presenta un daño considerable en la estructura arbórea, la supervivencia de árboles fue menor al 30% en la mayor parte de los sitios afectados y del 100 % en un solo sitio (superviviencia fue evaluada considerando los arboles vivos que fueron medidos para medir el área basal), esto provocó una reducción notable del área basal mayor al 70% o inclusive del 100%, junto con estos se resultados se observa un marcado decremento en las alturas promedio del dosel y la densidad de cobertura.

En particular, el elemento árboreo se vió afectado de diferentes maneras. Existen especies que no toleraron el fuego, la mayoría sus troncos han caído y son pocos los troncos muertos que se mantienen en pie. Especies como *Podocarpus*, *Quercus*, *Ticodendron*, y *Coccoloba* sobrevivieron a los incendios, conservando casi por completo la integridad de sus troncos y copas, estas especies a pesar de presentar ligeros daños desarrollan ramas, hojas y han comenzado a tener eventos reproductivos mediante la producción de flores y frutos. Otras especies presentaron daños mas severos: sin embargo, sus partes áereas se mantienen en vida mediante la formación de renuevos que se forman a partir de la base del tronco principal, tal es el caso de varias especies de lauráceas, el limoncillo (Symploacaceae) y *Weinmannia* sp. (Cunoniaceae). Algunas especies típicas del bosque original comienzan su restablecimiento a partir de plántulas como son el caso de *Cedrela* sp. (cedros), *Alchornea* sp., *Clethra* sp., *Dendropanax* sp. y *Oreopanax*, y es probable que algunas lo hagan mediante estolones (tallos subterráneos) como es el caso en algunos lugares de *Liquidambar* (E. Martínez com.pers.).

En estos sitios quemados los estratos herbáceo y arbustivo se desarrollan profusamente y en relación a las condiciones microambientales que soportan ahora, como son de crecemiento rárpido debajo de condiciones de alta luz. Sin embargo, algunas especies del bosque sobrevivieron, los cuales representan las características de vida típico de las especias del bosque maduro original. En general, las nuevas especies que están regenerandose presentes corresponden a especies características de etapas sucesionales incipientes donde las familias más representativas son Asteraceae, Solanaceae, Poaceae y Amaranthaceae. Algunos helechos de hojas duras se desarrollan también profusamente y en ocasiones cubren completamente el suelo, de igual forma *Phytolacca rivinoides* crece de manera extensiva. Entre los árboles que se han desarrollado a partir del incendio existen los que son típicos de ambientes perturbados de bosques montanos como: *Trema micrantha* (Ulmaceae), *Hedyosmum mexicanum* (Chloranthaceae), *Sambucus* sp. (Caprifoliaceae), *Brunellia* sp. (Brunelliaceae), Saurauia sp. (Actinidiaceae) y Liquidambar sp. (Hamamelidaceae). También es importante anotar que al igual que en el bosque original existen elementos típicos de zonas de tierras bajas que en este caso corresponden a especies secundarias típicas de las sucesiones de selvas como son *Cecropia* sp. y *Heliocarpus* sp., lo anterior indica que dentro de los procesos de sucesión se dan mezclas similares entre los elementos de tierras bajas y de tierras altas.

En casi todos los sitios, excepto el sitio 1 en San Antonio (donde la afectación del incendio fue de copa), el suelo presenta una cantidad importante de plantas epífitas (orquídeas, bromelias, piperáceas y helechos) que han sobrevivido en muchas de las ramas caídas y entre las piedras. Será interesante evaluar si su sobrevivencia puede ser viable bajo estas condiciones de altas intensidades de luz y su papel en la recuperación de los procesos ecosistemales. Además será interesante elegir si es conveniente transplantarlas para asegurar su sobrevivencia o bien si es más importante mantenerlas como un elemento necesario de acumulación de biomasa para las etapas sucesionales siguientes, aunque esto conlleve a su muerte. Por otra parte, la colecta de muchas de estás especies corresponderá a registros interesantes para las colecciones botánicas, ya que varias de ellas son especies que crecen en los estratos altos del bosque y es probable que no se encuentren bien representadas en las colecciones de herbario.

5.3. Las características biofíscias de los sitios de estudio

5.3.1. Los sitios localizados en la comunidad de San Antonio

Los resultados generales estrucutrales para los sitios de estudio de San Antonio Chimalapa se muestran en la tabla 3 y figura 1. En la primera fase del análisis sólo se consideran los seis sitios que se ubican en Karst dejando fuera a los sitios del Retén; sin este sitio es integrado más adelante.

Las parcelas conservadas mostraron diferencias en la altura promedio de dosel entre sitios, mientras que en el porcentaje de cobertura no hubo diferencias en los valores promedio de todos los sitios (Anova, $F = 1.7$, $p < 0.1841$). El sitio 5 fue el que presentó la altura del dosel más alta, similar a la del sitio 2 y significativamente mayor a la de los sitios 3, 4 y 6 (Anova, $F = 20.5$, $p < 0.001$). El valor de la altura del dosel del sitio 2 no mostró diferencias significativas con los valores de los sitios 3 y 6, pero fue mayor en comparación con el sitio 4. Las alturas de dosel de los sitios 3 y 4 no presentaron diferencias entre si. El sitio 1 fue el del dosel más bajo significativamente menor en comparación con todos los sitios (Anova, $F = 20.5$, $p < 0.001$).

Estos resultados sugieren la existencia de tres grupos de altura, a pesar de que en algunos casos los valores promedio no fueron sigificativamente distintos (por ejemplo en los sitios 2, 3 y 6 no hubo diferencias, pero el valor promedio del sitio 2 no fue distinto significativamente de el valor del sitio 5 por lo que estos dos sitios pueden un mismo grupo). De esta forma los sitios pueden ser agrupados de la siguiente manera: los de dosel alto (sitios 2 y 5), los dosel medio (3, 4 y 6) y el dosel bajo (sitio 1). Comparando los valores promedio de altura de dosel entre grupos (Fig. 2) se observa que difieren significativamente entre si, el grupo uno fue distinto del dos y tres, de la misma forma los grupos 2 y 3 son distintos (Anova, $F = 38.024$, $p < 0.001$).

En las parcelas quemadas los sitios 2, 3, 4, 5 y 6 tuvieron valores similares en la altura promedio del dosel y fueron significativamente más altos que el sitio 1 (Anova, $F= 10.91$, $p < 0.0001$).

Los valores de area basal muestran un patrón similar al de las alturas de dosel, es decir hay sitios con valores altos, medios y bajos, por lo que puede ser posible separarlos en tres clases , lo sitios con valores altos (sitios 2 y 6), los sitios con valores medios (sitios 3, 4 y 5) y un sitio con valor bajo, el sitio 1 (Fig. 3).

Si consideramos que los resultados de altura promedio del dosel y área basal, explicados arriba, podemos distinguir que los sitios pueden agruparse entres categorías de acuerdo a su productividad, esto confirma el diseño del proyecto, en el cual se consideran sitios de baja, media y alta productividad, aunque existe una discordancia entre los sitios que integran los grupos en las dos variables estructurales análizadas. En particular el problema se centra en los sitios 5 y 6, ya que el primero pertenece al gupo de dosel alto pero tiene un valor medio de área basal y el sitio 6 tiene un patrón inverso.

La parcela conservada del Reten fue integrada al análisis con las seis parcelas conservadas de Karst de San Antonio, los resultados fueron los siguientes: en relación a la altura media del dosel el Retén sólo fue significativamente distinto del sitio 1 (Anova, $p < 0.001$), presentando una altura similar a los cinco sitios restantes. En caso de la cobertura no mostró diferencias con los seis sitios y en su valor de área basal (18 m^2) es igual al de los sitios 3 y cinco. Si consideramos los grupos de productividad en que fueron divididas las parcelas ubicadas en Karst, el Reten quedaría ubicado como un sitio de productividad media ya que presenta un valor de altura de dosel intermedio (18 m) entre el grupo de alta y media (21 y 14 m, respectivamente).

<u>Características topográficas y edáficas.</u>

Las variables edáficas fueron analizadas considerando los grupos de productividad en que fueron divididos los sitios de San Antonio (excluyendo del análisis a el Reten). Los resultados se muestran en la figura 4. En caso de las parcelas conservadas no hubo diferencias entre los tres grupos en la mayoría de las variables analizadas (pendiente, grosores de hojarasca, fase orgánica, profundidad de raíces finas y porcentaje de raíces finas) excepto en caso del grosor del Humus donde el valor del sitio 2 fue significativamente menor a los correspondientes de los grupos 1 y 3 (Anova, $F = 20.34$, $p < 0.001$).

Cuando se comparan los valores de las características edáficas entre las parcelas conservadas y las quemadas se distingue que para los grosores de hojarasca y humus las parcelas conservadas de los tres grupos de productividad tienen valores significativamente mayores a los de las parcelas quemadas (Anova, $F = 20.3$, $p < 0.001$), tanto con sus correspondencias de productividad como con parcelas de otros grupos de productividad, mientras que las parcelas quemadas .

5.3.2. Los sitios localizados en la comunidad de Benito Juárez

Los resultados estructurales para los sitios de Benito Juárez se presentan en la la tabla 4 y figura 5. En los tres sitios no hubo diferencias en la altura promedio del dosel y el procentaje de cobertura promedio en las parcelas conservadas (Anovas, $F = 1.22$, $p > 0.32$ y $F = 1.88$, $p > 0.20$ respectivamente). En las parcelas quemadas tampoco hubo diferencias en los valores promedio de la altura del dosel entre sitios (Anova, $F = 1.73$, $p > 0.21$).

Para estos sitios no se distingue una diferencia sustancial entre sitios en relación a la productividad, evaluada de acuerdo a los valores altura del dosel y cobertura, aunque el caso de área basal los sitios 1 y 3 presentan valores similares mayores al registrado en el sitio 2.

<u>Características topográficas y edáficas.</u>

Estas variables fueron analizadas considerando los valores promedio entre parcelas conservadas y quemadas, ya que no existieron diferencias en las variables estructurales entre sitios. Los resultados muestran que para los casos de grosor de humus y porcentaje de raíces finas las parcelas quemadas muestran valores promedio significativamente mayores en comparación a los de las parcelas quemadas ($t = 3.4$, g.l. = 4, $p < 0.05$ y $t = 3.67$, g.l. = 4, $p < 0.05$; respectivamente; Fig. 6); mientras que para los grosores de hojarasca, fase orgánica, profundidad de raíces y pendiente no hubieron diferencias en los promedios entre parcelas conservadas y quemadas.

6. EXPERIMENTAL RESEARCH DESIGN

The results obtained from the preliminary studies of the fire-affected cloud forest and elfin forest sites presented above suggest a negative correlation between burn severity and ecosystem productivity, with productivity generally increasing with increased moisture associated with mineral soils, valley and lower slope locations, north/northeast aspects, or lower elevations. Three replicate sites will be selected to represent three different points along this gradient of fire severity and forest productivity: (1) low fire severity, high productivity; (2) moderate fire severity, moderate productivity; and (3) high fire severity-low productivity (see Figure 1). Replicate sites will be located in areas where biophysical factors (i.e., vegetation type, slope, aspect, elevation, etc.) are as similar as possible. In addition, sites will be sought where a fire-affected area and an unburned control area are located adjacent to each other under similar biophysical conditions.

Figure 1. Observed relationship between fire severity, forest productivity, and environmental conditions.

INCREASING FIRE SEVERITY →

Low (surface fire)	Medium (ground fire)	High (crown fire)

INCREASING FOREST PRODUCTIVITY (TREE HEIGHT)

High (25-40m)	Intermediate (15-25m)	Low (8-12m)

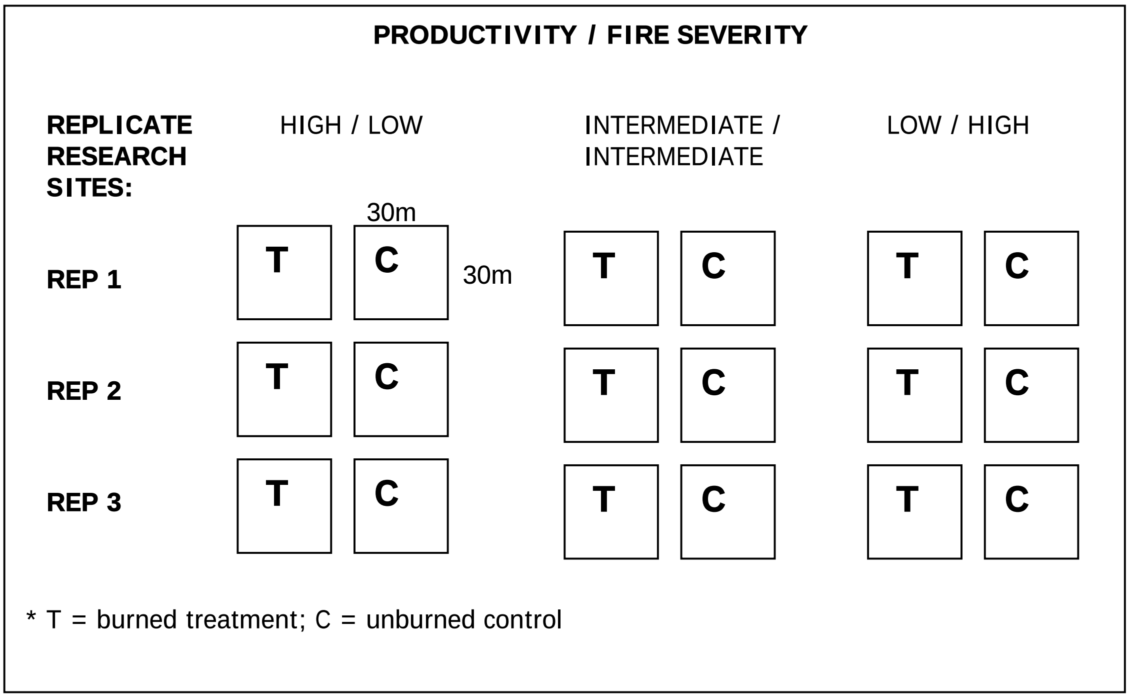
ENVIRONMENTAL CONDITIONS (SOILS, CLIMATE, TOPOGRAPHY)

Valley, mixed organic-mineral soils, high himidity	Slopes and plateaus, mixed organic-mineral-karst soils, intermediate humidity	Ridge tops and slopes, karst topography, high drainage, low humidity

The study design will integrate two approaches for evaluating and monitoring recovery of ecosystem function and structure following fire: (1) permanent plots, and (2) transects. Each of these approaches will be discussed separately below.

Permanent plots will be established to assess changes in ecosystem functions and processes as reflected by nutrient cycling, the hydrological regime, and biomass productivity. In each of the selected replicate study sites (see above) a 30 x 30 m plot will be established within both the burned and control area (see Figure 2). Each plot will be positioned such that there is at least a 30m buffer zone between the plot edge and the edge of the study site (i.e., where the environmental conditions represented by the study site change significantly). Efforts will also be made to maintain similar biophysical conditions between the paired control and burned plots. This will be accomplished by conducting an initial site evaluation, including establishing a field map of each site to identify boundaries, size of area, and baseline conditions. Measurements will be collected over time in the permanent plots to assess changes in species composition, nutrient cycling, productivity, and hydrological processes (see proceeding sections). (Study design modified according to Walker et al. 1996).

Figure 2. Experimental design for permanent plots



Transects will be used to evaluate changes in species composition, diversity, and ecosystem structure as reflected by landscape distributional patterns and successional processes.

The study design developed for both the permanent plots and transects will take into account variation in fire severity in the landscape in relation to topography, climate, and other microsite factors. The two distinct methodologies will be standardized against each other in order to allow for direct comparisons and integration of the data sets. The location of both the permanent plots and survey transects will be based on an analysis of satellite images and aerial photos taken before and after the fires, consultation with local people and other knowledgeable individuals, and extensive ground-truthing in the field to verify initially assessments and select appropriate research sites.

Finally, a key aspect of developing and implementing this research is the active involvement of the people in the communities where the research will be conducted, in close coordination with the authorities at both the community and municipal levels. Community teams will work closely with the external research team during all phases of the project. Joint capacity building activities will be organized as required. The community teams will also serve as a vital communication link between the research team and the community as a whole, and be actively involved in community meetings and workshops where project activities and results will be presented and discussed. Further, as part of the collaboration between participating Mexican and foreign academic institutions, activities related to student and researcher exchanges, curriculum development, and joint research initiatives, courses, and workshops will be promoted.

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